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An Upgrade of the Imaging for Hypersonic Experimental Aeroheating Testing (IHEAT) Software

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Presentation Outline

Introduction

The purpose of this presentation is to demonstrate the capabilities of the Imaging for Hypersonic Experimental Aeroheating Testing program, version 4.0.

Goals of Software Upgrade

- Capture the capability of the legacy program in a MATLAB version of IHEAT
- Improve the techniques used to extract data from regions of interest
- Increase efficiency of the phosphor thermography data reduction process
- Correlate the global heat transfer pattern in a 2D image to a 3D CAD model

Software Impact

- IHEAT is the primary method to reduce LAL phosphor thermography data
- New tools simplify the data reduction process and reduce the time required to analyze the phosphor thermography data
- A stand-alone executable file compiled in MATLAB minimizes the effects due to changes in the language over time, making the software more reliable

LaRC Aerothermodynamics Laboratory

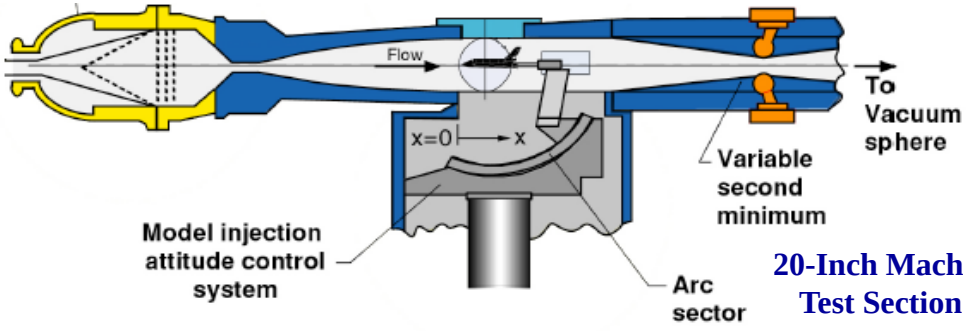
- Operation:
  - Conventional blow-down wind tunnels
  - Perfect-gas, dry-air facilities provide high flow quality and low-enthalpy test conditions
  - Optical access on three sides for phosphor thermography, PLIF, IR, Schlieren, etc.
- Wind Tunnel Features:
  - 31-inch, Mach 10:
    - Re: 0.5-2.0 x 10^6/ft
    - Core Flow: 14” x 14”
    - Max run duration: 2 minutes
  - 15-Inch Mach 6:
    - Re: 1.3-7.0 x 10^6/ft
    - Core Flow: 10” diameter
    - Max run duration: 2 minutes
  - 20-Inch Mach 6:
    - Re: 0.5-8.3 x 10^6/ft
    - Core Flow: 14” x 14”
    - Max run duration: 15 minutes

Experimental Facilities

31-Inch Mach 10 Air

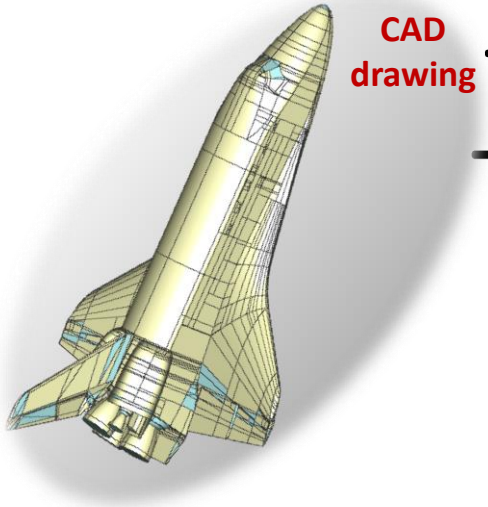
15-Inch High Temperature Air

20-Inch Mach 6 Air



20-Inch Mach 6 Test Section

Model Fabrication Process



CAD drawing → To Model Shop → MACOR or Metal Fab → Instrumentation Lab

Stereolithography Machine

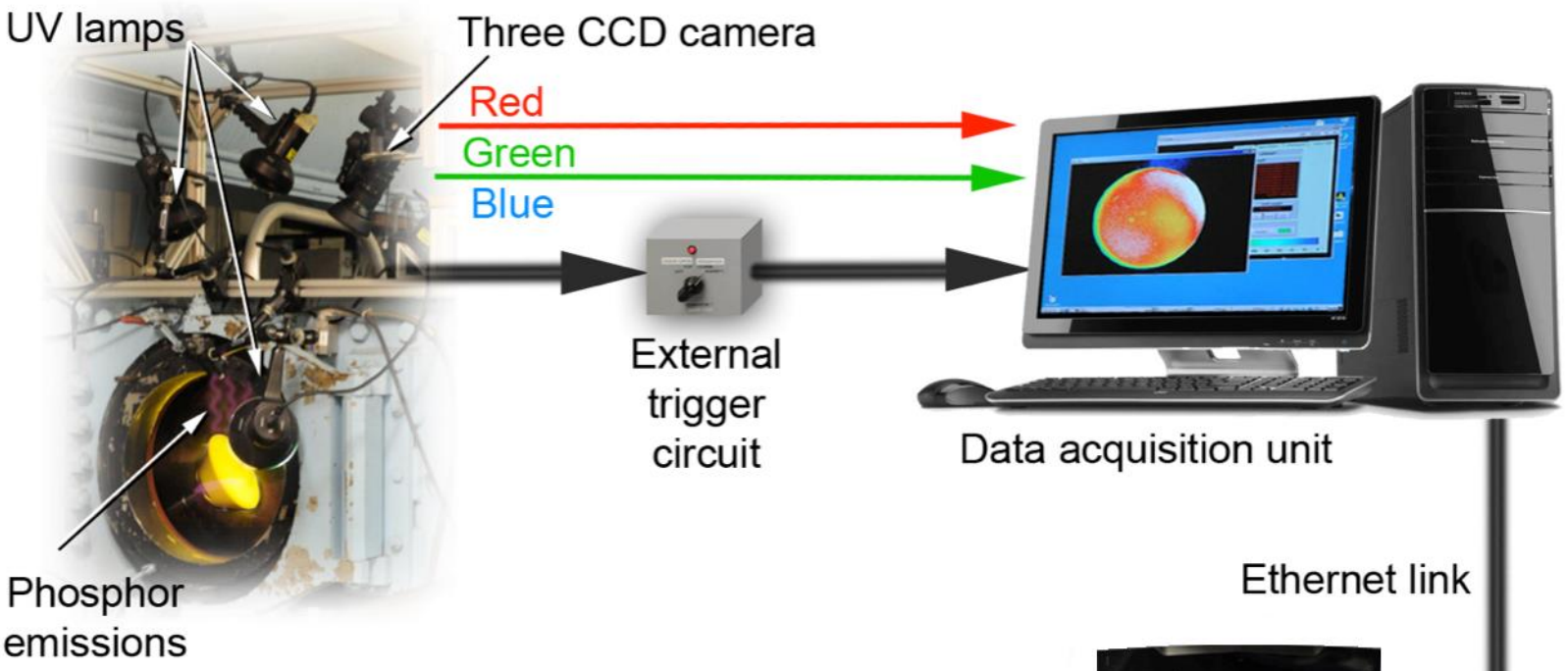
To Ceramics Laboratory

Wax mold → Fired ceramic model with phosphor coating

To QA

Coordinate Measuring Machine

Phosphor Thermography



Enthalpy-based convection: $\dot{q}_{conv} = c_h(h_{aw} - h_w)$

Step function: (using Laplace transforms)

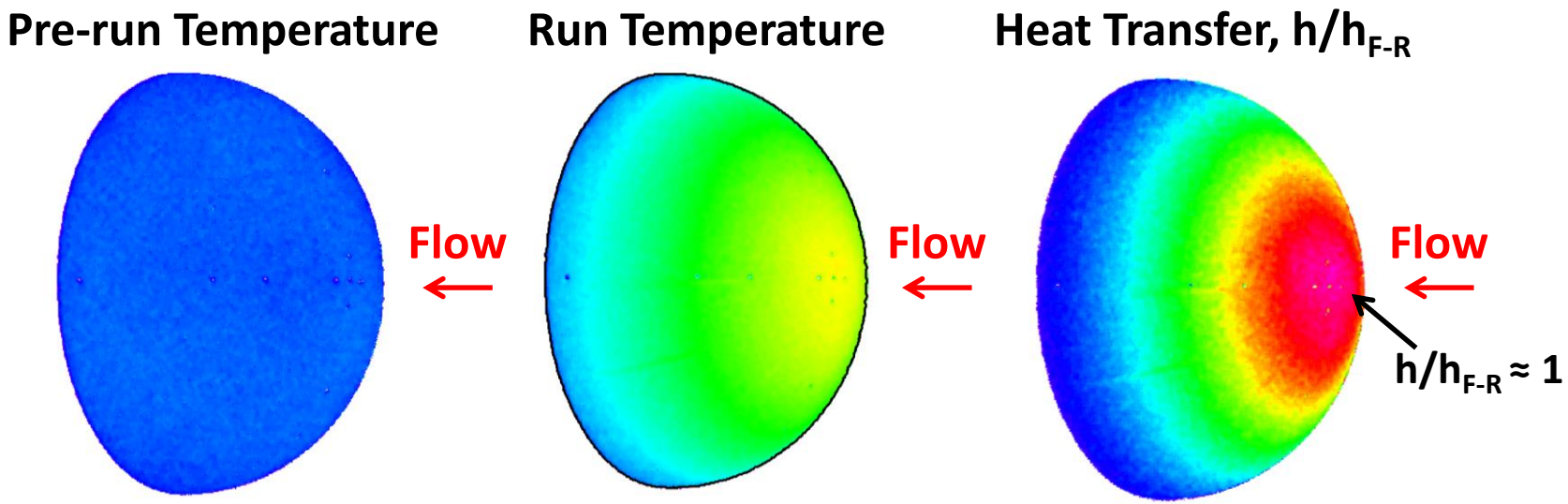
$$\frac{\theta_w}{D} = 1 - e^{\Lambda^2} erfc\ \Lambda$$

Where:

$$\theta_w = T_w - T_{init}$$
$$\Lambda = C\sqrt{t}/\beta$$
$$C = c_h(h_w/T_w)$$
$$D = h_{aw}(T_w/h_w) - T_{init}$$

IHEAT Software Assumptions:

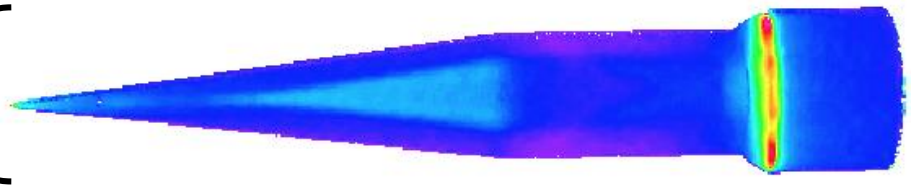
- One-dimensional (1D), semi-infinite conduction is assumed
- Convection boundary condition (BC)
- Step function in heating as model passes through the tunnel boundary layer before it reaches the wind tunnel centerline
- Stagnation-point Fay-Riddell heat transfer is used as the reference value to compute non-dimensional data



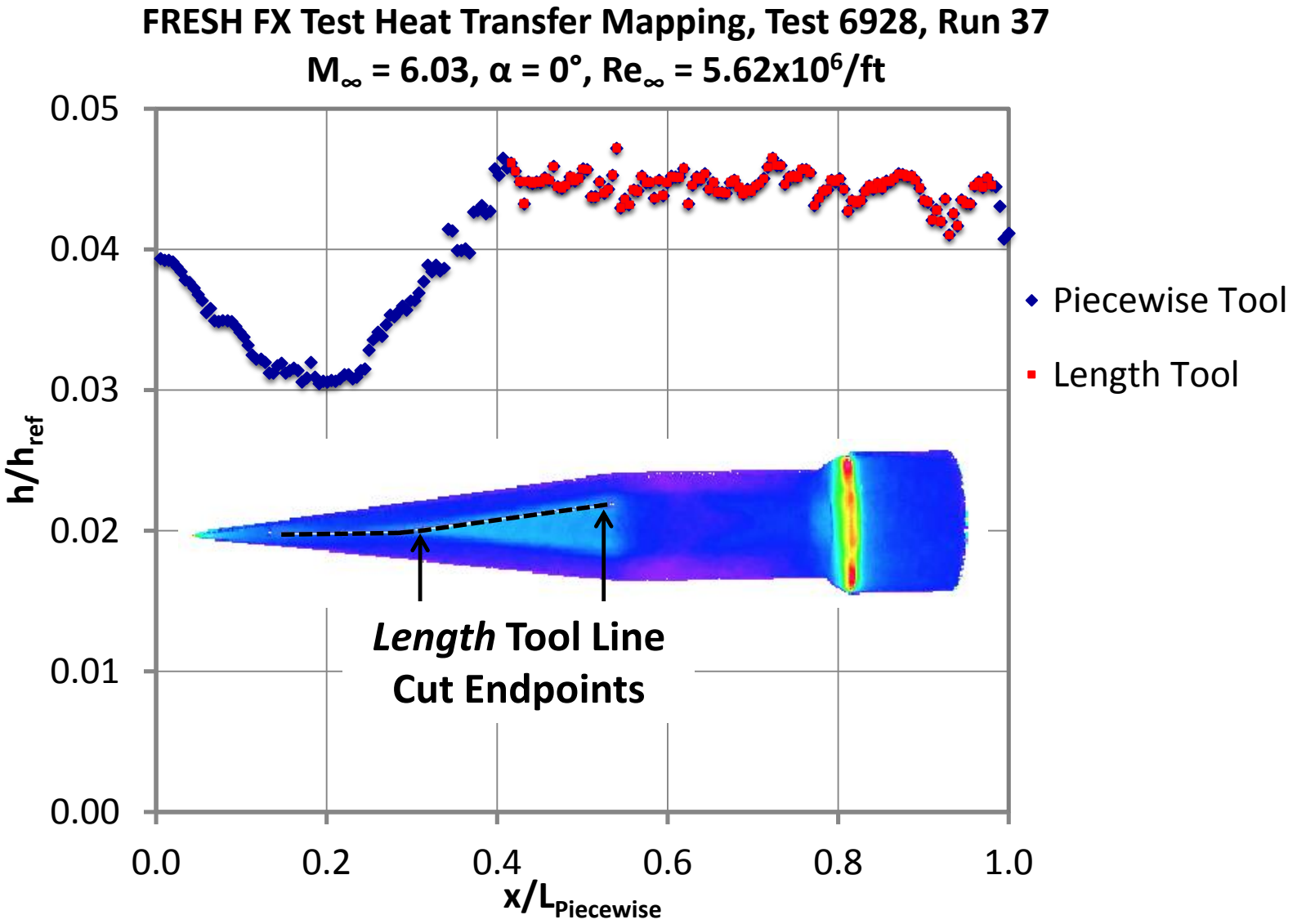
New Tools in IHEAT 4.0

- *Load Run* – automatically load all input files for a run
- Comprehensive *Data* button – see all available data at each pixel on the model
- *Activate Line Cuts* – exactly replicate line cut locations
- *Pre-run Temperature Check* – new diagnostic check of data acquisition process (model lighting, phosphor coating, etc.)
- *Piecewise* Line Cut
- *Batch* and *Temporal Collapse* Figure
- *Run Temperature Uncertainty* Image
- *3D Mapping* to CAD model

Examples of the tools listed in red will be shown using HIFiRE1 Data

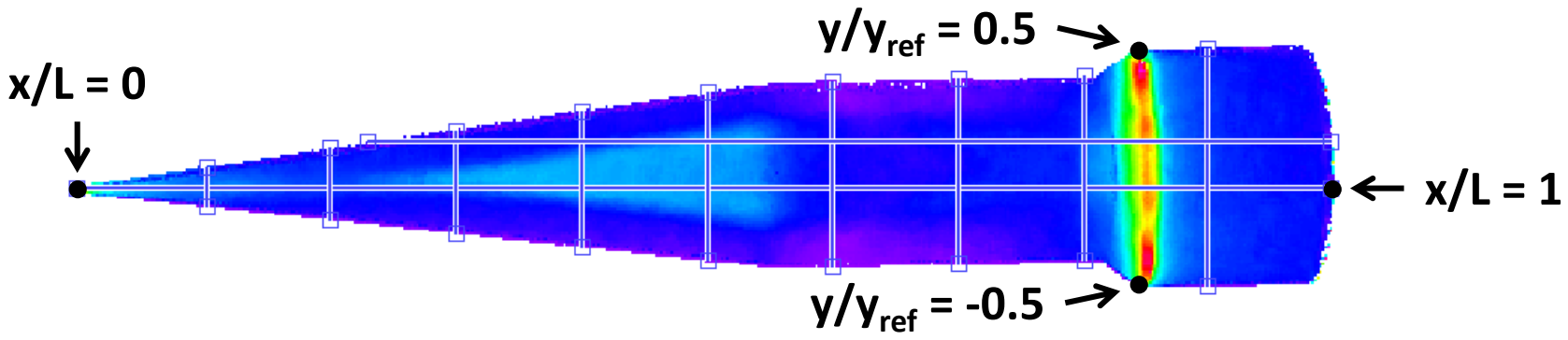


Segmented line cuts – *Piecewise* Tool



Batch Tool Improves Efficiency of IHEAT 4.0

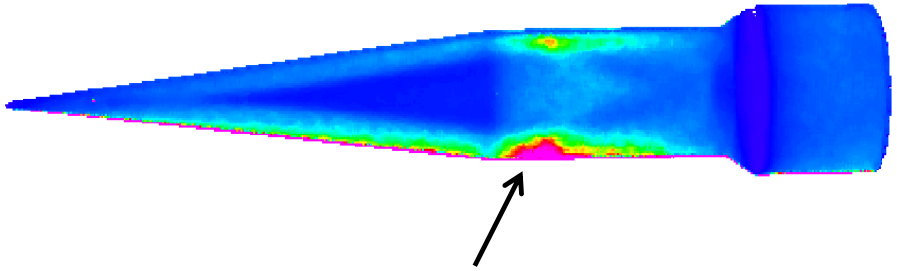
Auto Profile Grid of Line Cuts on HIFiRE-1 Model



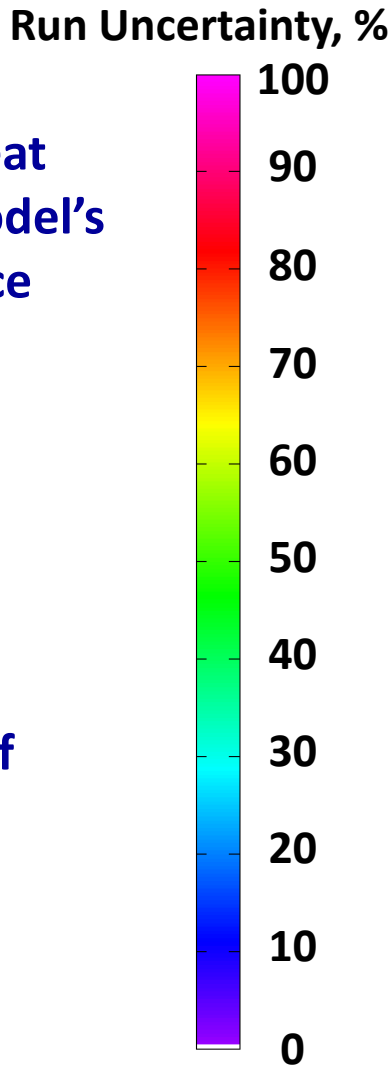
- Temporal collapse of data for the run is computed automatically
- *Batch* process speeds up heat transfer analysis – data reduction times of hours are reduced to minutes for runs in which every frame of 30 Hz data is recorded
- IHEAT 4.0 is run remotely on a separate server, so a user can complete other tasks and a *Batch* process simultaneously without reducing available memory on the host system

Run Temperature Uncertainty Image

Total uncertainty at each pixel = uncertainties in heat transfer values due to wind tunnel conditions, the model's thermal properties, and the temperature difference between the pre-run and run temperatures.

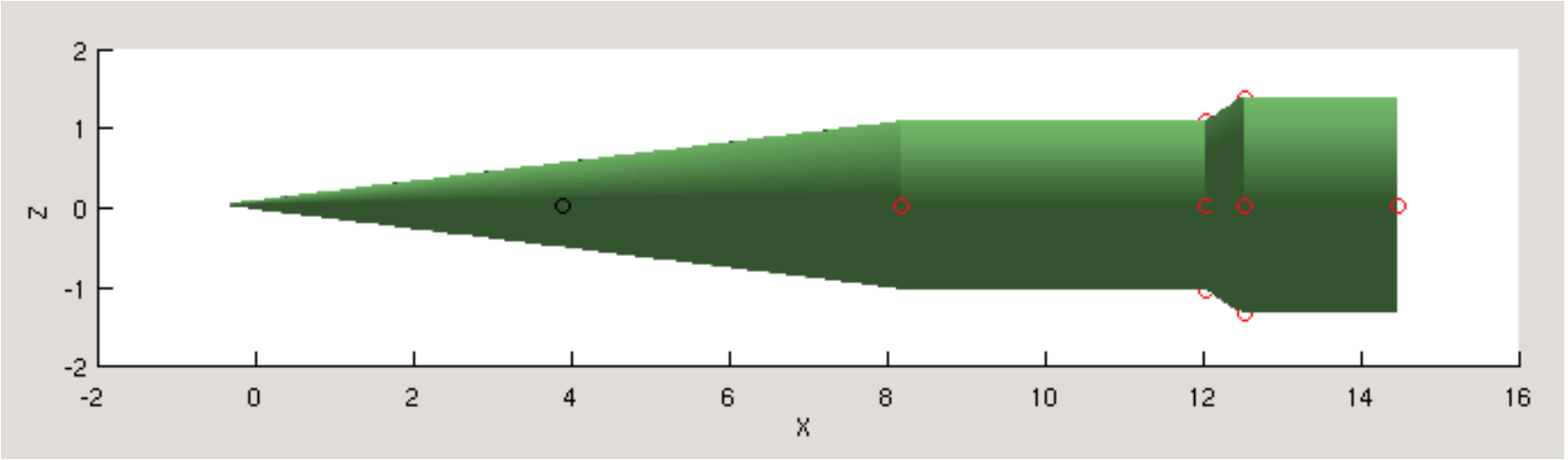


Higher uncertainty values near the edge of the model and where ΔT is smaller



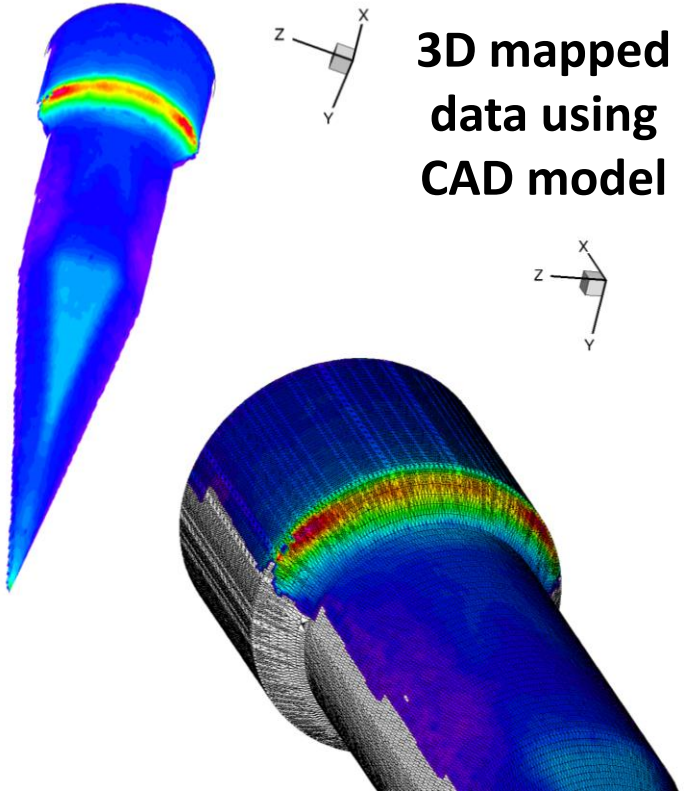
Map 2D Global Data to a 3D CAD model

- User provides fiducial mark correlations between 2D locations on image and 3D (x, y, z) coordinates on model
- User specifies the approximate location of the camera relative to the CAD model to yield a view similar to the 2D image
- User selects the appropriate focal length (from a range of plausible options) to map the image to the CAD model
- User can map the pre-run or run temperature, heat transfer or uncertainty data to the 3D CAD model

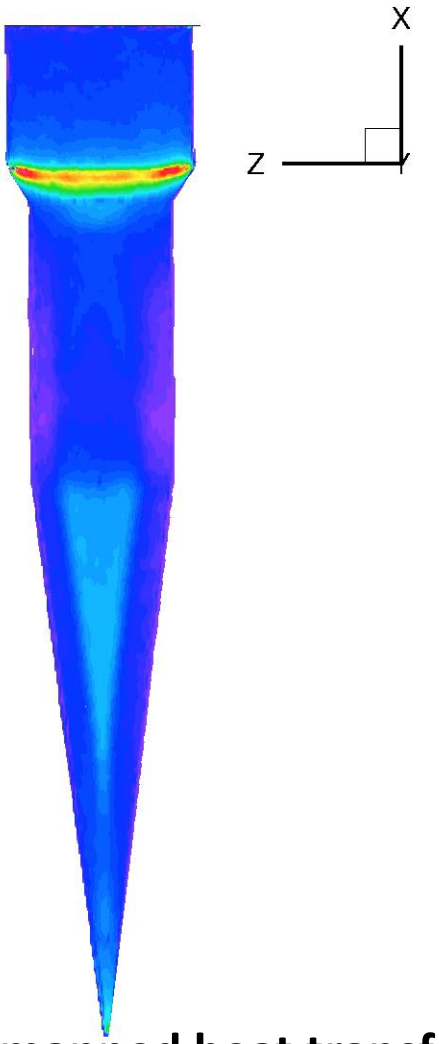


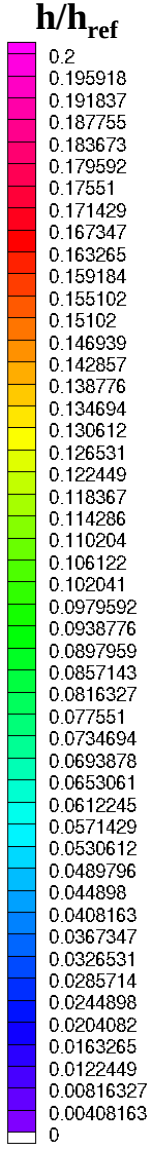
3D Mapping Output in Tecplot

2D global heat transfer image from IHEAT 4.0 (in MATLAB)



3D mapped data using CAD model



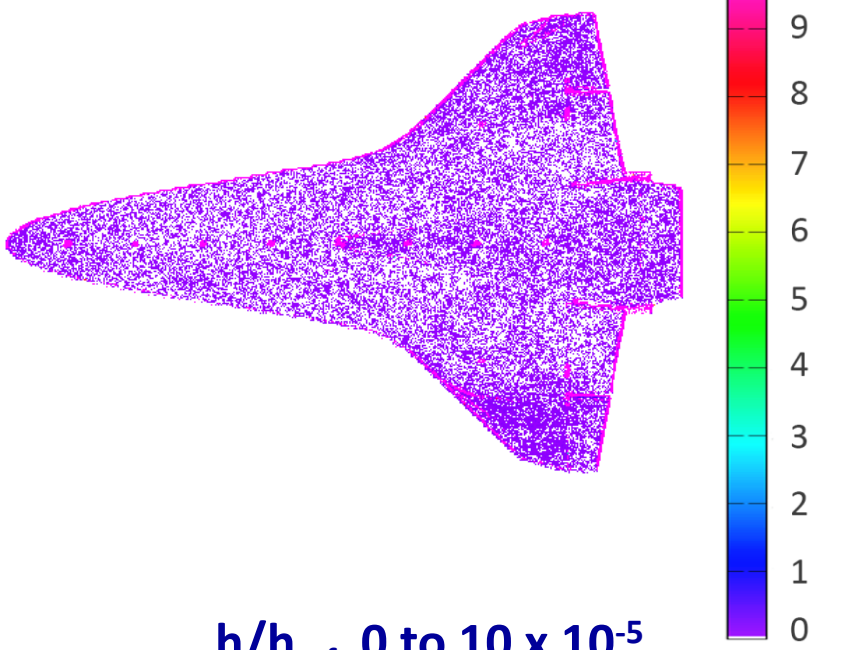


3D mapped heat transfer data, rotated about z-axis (in Tecplot)

Validation of IHEAT 4.0 Heat Transfer Data

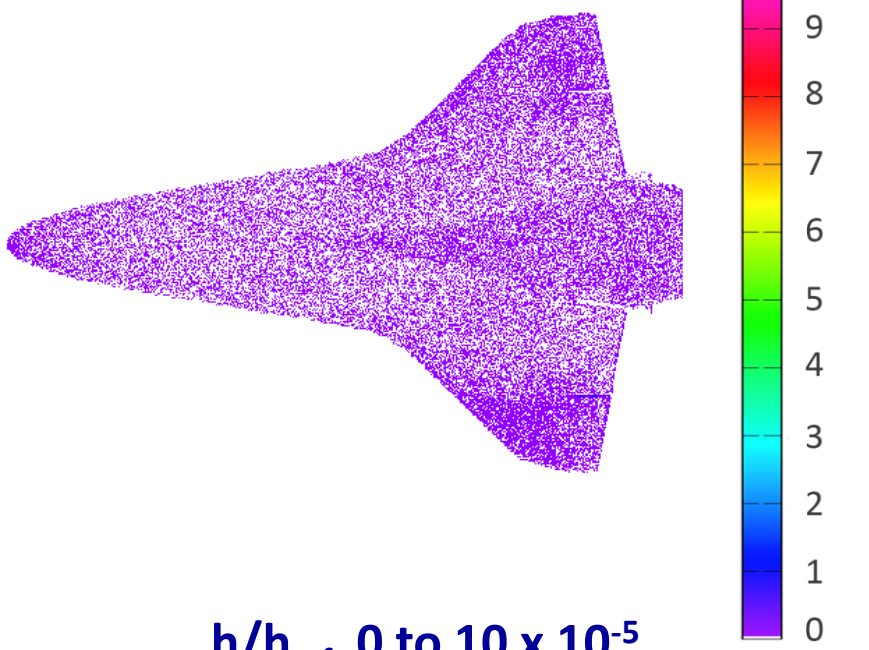
Absolute Difference between IHEAT 4.0 and IHEAT 3.2

Median and Sobel Filtered Data
Space Shuttle Run



h/h_{ref}, 0 to 10 x 10^{-5}

Unfiltered Data
Space Shuttle Run

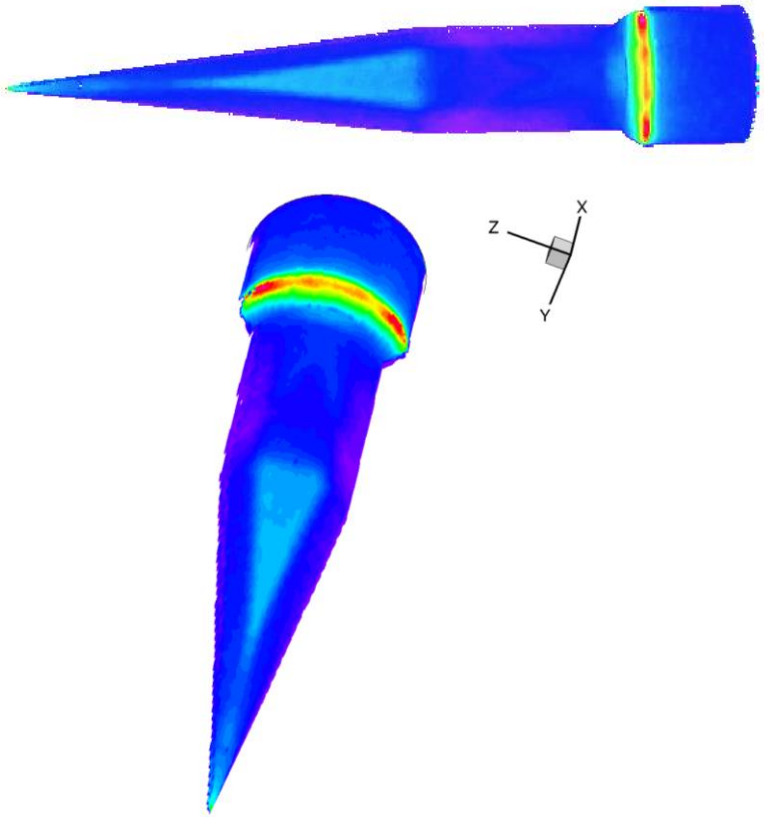


h/h_{ref}, 0 to 10 x 10^{-5}

Conclusions

- Through the introduction of eight new tools and other program modifications, the upgraded IHEAT software is more user friendly, functional and reliable.
- IHEAT 4.0 allows the user to obtain data from segmented *Piecewise* line cuts along interesting features in the data.
- Through new tools such as *Batch* and *Load Run*, LAL phosphor thermography data can be analyzed more quickly and efficiently.
- 2D global information now can be mapped to 3D CAD models as a Tecplot output from IHEAT 4.0 in minutes rather than days.
- Heat transfer calculations in the IHEAT 4.0 program have been validated through comparisons with IHEAT 3.2 output data.

Upgraded capability to reduce phosphor thermography data in NASA LAL wind tunnels



Future Work

- Improve the 3D mapping capability included in IHEAT 4.0
  - Incorporate 2D and 3D heat transfer calculations to improve the accuracy of the mapped data
  - Modify 3D mapping module to load in binary CAD files to reduce the processing time for the 3D mapping program
  - Reduce the number of user inputs describing camera orientation required to map data in 3D
  - Add the capability to easily extract line cut data from the 3D mapped output in Tecplot
- Incorporate an algorithm to extrapolate ground test heat transfer coefficients to flight values
- Generalize heat transfer algorithm in IHEAT 4.0 to use with other global temperature measurement systems, such as a higher temperature phosphor system (under development)

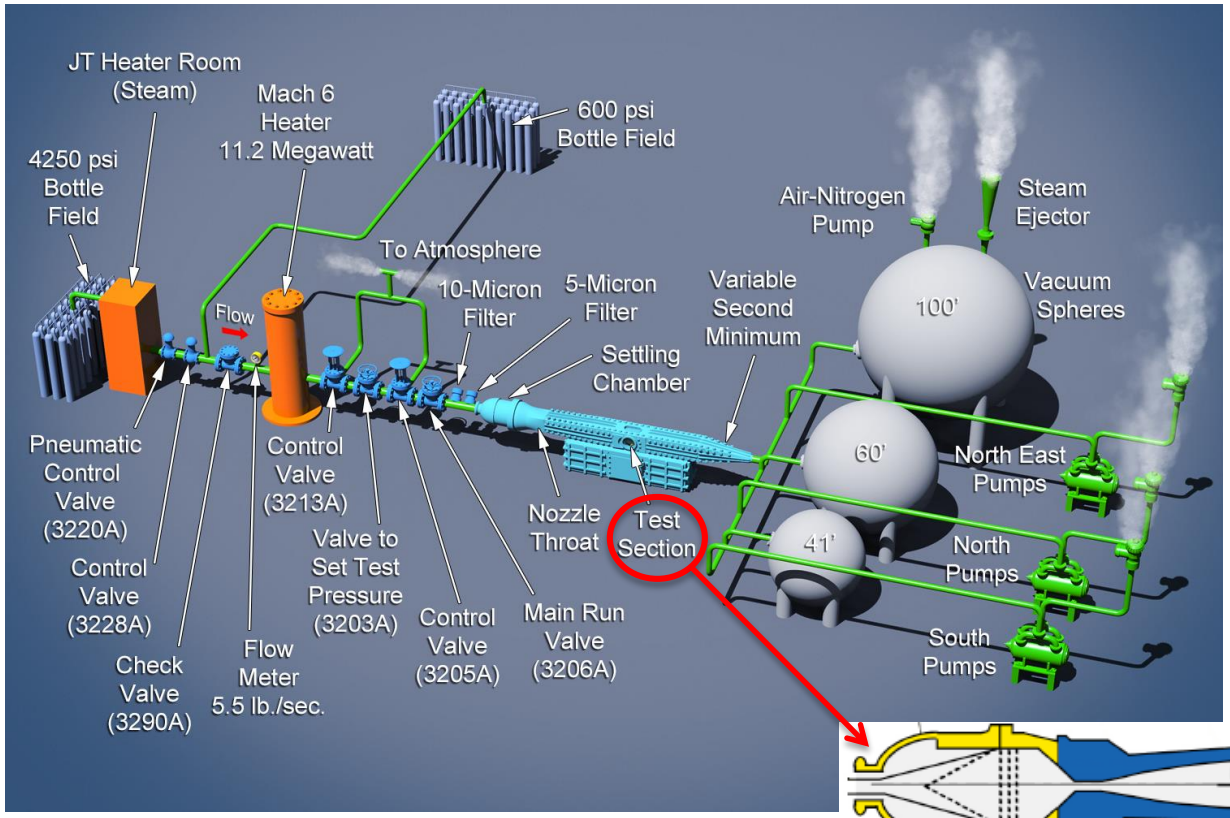
Upgrade to IHEAT Software

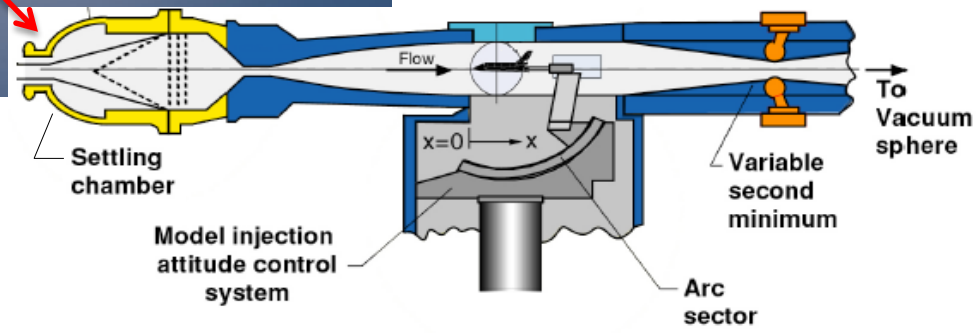
Thank you! Questions?

Back-Up Slides

Experimental Facility

Langley Aerothermodynamics Laboratory 20-Inch Mach 6 Air Tunnel



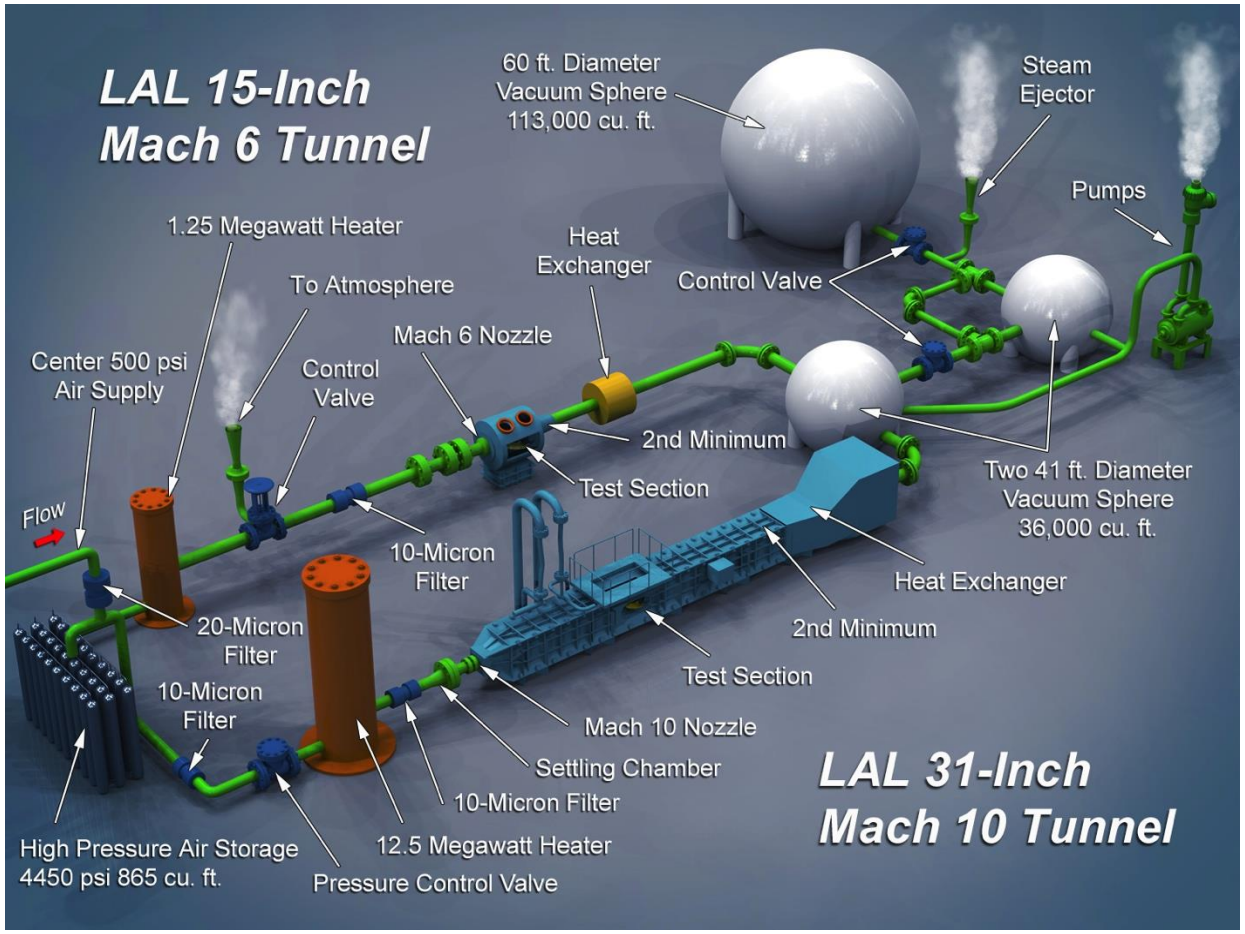


Nominal Tunnel Conditions:

- Mach 6
- Re: 0.5-8.3 x10^6/ft
- $T_{t,1}$: 805-935 °R
- $P_{t,1}$: 30-480 psia
- Test section: 20.5” x 20.0” with 12”x12” core flow
- Run duration: Up to 15 minutes
- Test gas: Dry air

Experimental Facilities

Langley Aerothermodynamics Laboratory Air Tunnels



Nominal Tunnel Conditions:

31-inch, Mach 10:

- Re: 0.5-2.0x10^6/ft
- $T_{t,1}$: 1775-1790˚R
- $P_{t,1}$: 350-1450 psi
- Test section: 31” x 31”
- Max run duration: 2 minutes
- Test gas: Dry air

15-inch, Mach 6:

- Re: 1.3-7.0x10^6/ft
- $T_{t,1}$: 870-1210˚R
- $P_{t,1}$: 100-400 psi
- Test section: 15”-diameter nozzle exit, open jet facility
- Max run duration: 2 minutes
- Test gas: Dry air